

# FIELD WORK

By Kristen Coyne

## Research in big magnets is hot... and getting hotter

Way back in 600 B.C. the Greeks first noticed that lodestone attracted iron; a few centuries later, the Chinese began exploiting that knowledge to make the earliest compasses. Since then, the science of electricity and magnetism has come a long way, and men have devised magnets exponentially more powerful than the natural ones that first fascinated ancient minds.

Interest in big magnets endures in Asia, Europe and elsewhere, where scientists and engineers are planning and building new research institutions they hope will rival the biggest magnet lab in the world, the National High Magnetic Field Laboratory.

There's good reason researchers are pushing hard for scarce R&D euros, dollars, yuan and yen to build bigger and better magnets: High magnetic fields can probe the structure and behavior of matter like no other tool. Used alone or in tandem with instruments such as mass spectrometers, lasers and MRI machines, these magnets are both powerful and versatile,

with applications in physics, biology, chemistry, geology, engineering and materials science.

Whatever the discipline, high-field magnets make possible the kind of heavy-hitting, basic research that deepens our knowledge of the world while drawing us closer to practical applications that will improve the way we live. Higher fields are in high demand among researchers because bigger magnets bring better results.

"It's true," said Greg Boebinger, director of the National High Magnetic Field Laboratory, which is headquartered at Florida State University

Greg Boebinger

in Tallahassee. "I can think of a half dozen countries around the world that are now investing so much money in magnet research that they will one day rival, or even surpass, some of our best magnets."

Established by the National Science Foundation in 1990, the "Mag Lab," as it's more commonly known, is home to some of the biggest, strongest, most sought-after magnets on the planet. The shiniest of its crown jewels is the hybrid magnet, a 35-ton behemoth that produces the highest sustained magnetic field in the world. Scientists measure magnetic strength in units called tesla. A fridge magnet is a tiny fraction of a tesla. A 1-tesla magnet can pick up a car, while a 3-tesla runs the average MRI machine. The Mag Lab's hybrid, in comparison, produces a phenomenal field of 45 tesla (see sidebar on magnets, p. 7).

Clearly, today's research magnets are no lumps of lodestone. In fact, they aren't permanent magnets (like those on the fridge) at all, but rather electromagnets, superconducting magnets, or combinations such as the hybrid. From the outside, they look like Thermos bottles on steroids. Inside, they are highly sophisticated instruments requiring great skill and resources to operate. At the center of each sits some of the hottest real estate in science: the magnet's bore. This empty space, measuring at most a few inches in diameter, is where the action happens. Scientists put their experiments in the bore then watch the data roll in.

Contrary to what many might think, scientists don't use research magnets to study magnetism. The magnets aren't the ends, but the means – the means to discovery. Just as a microscope allows us to view details invisible to the naked eye, so do magnetic fields reveal the nature of things – and of the very laws of science that account for them.

How can you "see" things with magnetic fields? X-ray machines detect broken bones by using a type of energetic light that shines right through your body.





### UNITED STATES

The National High Magnetic Field Laboratory is the only user facility of its kind in the U.S. The Mag Lab continues to lead the world in magnet technology, but labs around the world are making inroads.



### NETHERLANDS

The Radboud University in Nijmegen is investing heavily in the development of a free-electron laser radiation source and a 45 T hybrid magnet system to enhance the capabilities of its High Field Magnet Laboratory.



### FRANCE

The National Pulsed Magnetic Field Laboratory in Toulouse has developed a 30 T magnet for use at the European Synchrotron Research Facility (ESRF) in Grenoble. Such a capability is not yet available in the U.S.



### GERMANY

The Dresden High Magnetic Field Laboratory combines a free-electron laser with its high magnetic fields, a combination not yet available in the U.S. Dresden is working toward development of a 100 T short-pulse magnet.



### CHINA

The Chinese government is spending \$48 million to develop its new Hefei High Magnetic Field Lab, which is scheduled for completion in 2012.



### JAPAN

Japan may be a small country, but its interest in high magnetic field research is huge. Japan is home to six magnet labs!



Magnets also exploit electrons – the moving electrons that make up their fields – to examine objects within that field. It all comes down to atoms and the fact that so much of the universe is governed by opposites that attract and like things that repel. If you put something inside a magnet, the positive and negative particles in its atoms interact with each other and with the magnetic field in a way that reveals something about its properties in particular, or about the properties of matter in general.

There are lots of questions you can answer with a magnet. For example, what kind of materials will work best in tomorrow's faster, smaller computers? What changes does a potential Alzheimer's drug stimulate in the brain? What molecules make up a sample of crude oil – and is it worth drilling for? What is the best way to build a superconducting cable – and save untold billions in electricity costs?



Horst Störmer

"High magnetic fields have always been an essential tool in the tool box of physicists," said Columbia University physicist Horst Störmer, who shared the 1998 Nobel Prize in Physics for the discovery, made with the help of high-field magnets, of a new form of quantum fluids. "Nothing is comparable to standing next to these giant, roaring magnets, generating stable magnetic fields higher than anywhere else on the

globe, and have data emerging that seem implausible at first, but actually represent a new discovery in physics."

This is tantalizing stuff for scientists. That's why China is spending some \$50 million on its new High Magnetic Field Lab, part of \$750 million that country is investing in science infrastructure. That is also why the Europeans are planning to consolidate their four magnet labs (two in France, one each in Germany and the Netherlands) under a single umbrella institution, the European Magnetic Field Laboratory. Taking a nod from the Mag Lab, which has sites at the Los Alamos National Laboratory in New Mexico and the University of Florida

in Gainesville, the Europeans hope this multiple campus model will eliminate duplication of effort and allow each facility to produce its best research.

If there is a competitive aspect to these magnet development efforts, there also is a lot of cooperation. International collaboration can only further science, and few institutions offer better living proof of this than the Mag Lab. Its staff is made up of experts from around the world, and of the thousand scientists who travel to the lab every year to conduct experiments, nearly a quarter come from overseas.

A scientist's research can only be as good as her instruments. Today's magnets have the highest fields that materials and technology will allow. But stronger materials and more advanced technologies now under development will lead to even higher fields. These mightier magnets will extend scientific techniques while lowering operating costs – which now run well into the millions of dollars annually at the Mag Lab alone. That incentive has pushed the Mag Lab to become one of the world's leading designers and builders of magnets. With \$20 million in contracts and grants, the lab's engineers are currently building a pair of series connected hybrid magnets, a novel design that will reach higher fields with less electricity. One of these magnets, funded by the NSF, will be located in the Mag Lab's Tallahassee headquarters; the second is headed to Germany's Helmholtz Centre Berlin, where it will be used for neutron scattering.

The scientific community's appetite for knowledge extends to other magnets as well. Under the auspices of the National Academies, which advise the U.S. government and public on science and technology issues, the Committee on Opportunities in High Magnetic Field Science issued a report in 2005 underscoring the need for more powerful magnets. Noting that "the prospects are bright for future gains from high-field research," the report called specifically for the development of a 30 tesla nuclear magnetic resonance (NMR) magnet, a 60 tesla hybrid magnet and a 100 tesla long pulse magnet – all projects that will require the development of new materials and interinstitutional collaborations.



Myriam Sarachik, a distinguished professor of physics at City College of New York, looks forward to the day those tools open more new areas of discovery for physicists, biologists and other scientists. A member of the National Academy of Sciences, Sarachik said she hopes the U.S. can maintain its impressive lead in high-field magnet

research: It's one of the scientific niches in which the country still dominates. That leadership not only benefits U.S. science and industry, she noted, but scientific collaborators across the globe.

"Other parts of the globe are slowly coming up to our level—and not so slowly in some instances," said Sarachik. "These unique high-field magnets have been a tremendous advantage to the U.S. position in scientific research and innovation."

## MAGNETS AT A GLANCE

- ▶ **RESISTIVE** magnets (also called Bitter magnets or electromagnets) require lots of electricity and cooled water. Resistive magnets can reach and sustain high fields over many hours, but they are costly to operate and use is limited by the amount of power available.
- ▶ **SUPERCONDUCTING** magnets require little or no electrical power to run once they are brought up to full field because they are made with superconducting materials that conduct electricity without resistance as long as they are kept extremely cold (as low as one degree above absolute zero temperature, depending on the material). While they are cheaper to operate, the strength of field is limited by properties of superconducting materials.
- ▶ **HYBRID** magnets combine resistive and superconducting technology, taking advantage of the strengths of each; resistive coils are nested inside the superconducting coils, the latter of which account for most of the magnet's weight and volume. Hybrid magnets produce the highest sustained magnetic fields possible.
- ▶ **PULSED** magnets produce much higher fields (up to 89 tesla) than the other magnet technologies, but the high field lasts only seconds or fractions of a second.
- ▶ **SERIES CONNECTED HYBRID** magnets, like the conventional hybrid magnets described above, combine resistive and superconducting technology. But the series connected magnets, currently being built, differ in that they are driven in series with the same power supply, rather than independently. This creates the high fields using less power.

